Far-Infrared Emission of the ISM in Galaxies of Varying Morphology and Star Formation

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Abstract

Observations of far-infrared emission lines can be used to infer the physical conditions of the ISM in galaxies. We describe a sample of 212 galaxies observed with the ISO Long Wavelength Spectrometer (43-197μm), extracted from the ISO Data Archive and reduced in a systematic and uniform fashion with the ISOLWS Interactive Analysis and ISO Spectral Analysis software. This sample spans a range of morphologies, star formation rates, and UV heating intensities (0.1 < F60μm/F100μm < 1.4). [CII] 158μm and [OI] 63μm are observed in emission for a majority of this sample and arise from PDR regions. We examine [CII]/FIR, [OI]/[CII], and ([OI]+[CII])/FIR over the range of morphologies and FUV radiation fields. The [CII]/FIR ratio is seen to peak around F60μm/F100μm = 0.4-0.5 and decrease in more active (F60μm>0.5) and quiescent (F60μm<0.4) galaxies. As [CII] emission becomes deficient in active galaxies, [OI] begins to dominate the cooling at F60μm/F100μm > 0.7 in the hot, dense PDR regime.

Observations and Data Reduction

We present Infrared Space Observatory (ISO) Long Wavelength Spectrometer (LWS) medium-resolution grating mode (43-197μm, $\lambda/\Delta\lambda$~200) observations for 212 galaxies, distributed across the sky as seen in Figure 1. The galaxies included in this sample were extracted from the ISO Data Archive and processed through the LWS Pipeline Version 7.0 or higher. Table 1 lists the present sample along with the RC3 morphological type and flux in each of the four IRAS bands (12, 25, 60, 100μm). In Table 2, we summarize the seven far-infrared fine structure line transitions that were observed most often, including the [CII] 158μm and [OI] 63μm cooling lines found in many of these galaxies. In all cases, the lines are unresolved.

Most of these galaxies are classified as "faint sources" (F60μm < 100 Jy). Since the errors in the pipeline dark current subtraction are of the same order as the continuum fluxes of these galaxies, the dark currents were re-estimated and removed using the LWS Interactive Analysis (LIA). Using these more accurate dark currents, we then corrected for any instrumental responsivity variations and flux-calibrated the data to the LWS calibration source Uranus. After using LIA, we performed our analysis using the ISO Spectral Analysis Package (ISAP). Glitches due to cosmic rays were removed from the data. Spectral scans were co-added and averaged together using a 3-σ clip in spectral bins of about 0.05μm. For L01 observations, a fringing pattern arises that affects the shape of the continuum and the identification of weak spectral lines. This sinusoidal fringe was removed using a defringing algorithm supplied within ISAP. Finally, line fluxes were calculated assuming a Gaussian line with the effective instrumental profile (0.29μm for λ < 90μm, 0.60μm for λ > 90μm) since the lines are unresolved. In the case of non-detections, 3-σ upper limits were calculated.

Introduction

Far-infrared (FIR) spectroscopy provides the opportunity to observe dust-enshrouded galaxies due to low extinction at these wavelengths. The FIR atomic fine-structure lines, including [CII] 158μm and [OI] 63μm, are the dominant cooling lines for the neutral, interstellar medium. Other fine structure lines such as [OIII] 88μm and 52μm and [NII] 122μm cool HII regions. These lines, along with the [OI] 145mm and [NIII] 57mm lines, provide measurements that may be used to determine the temperature, density, and radiation density of the gas by using Photo Dissociation Region (PDR) and HII region models.

In this poster we report on these fine structure lines observed in 212 galaxies taken with the ISO Long Wavelength Spectrometer (LWS). The sample consists of two parts. They are 1) smaller galaxies in which all the FIR emission is within one 75" LWS beam and 2) nearby, resolved galaxies whose FIR emission fills the LWS beam. This work focuses on the first sample.

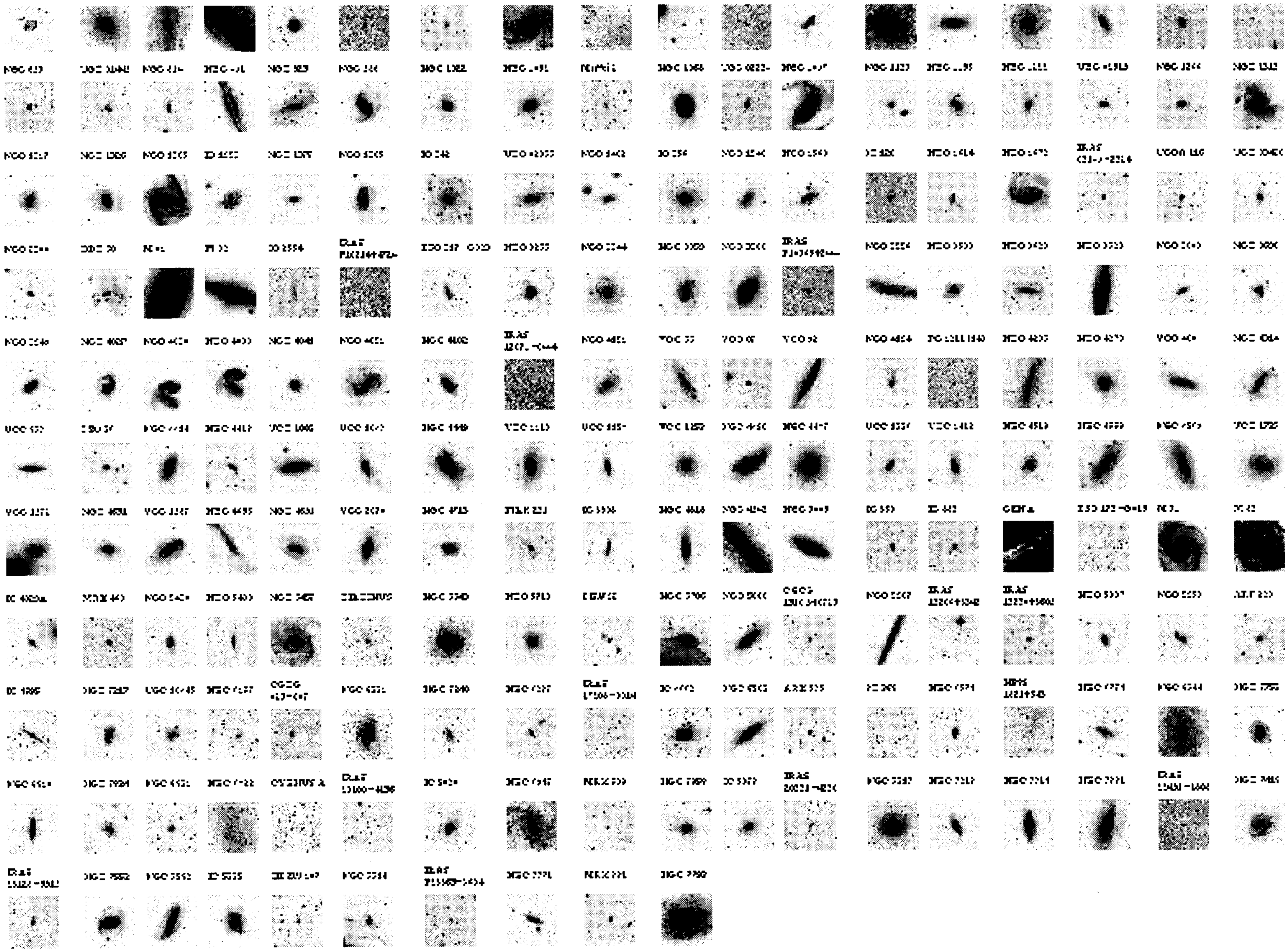

Figure. Optical Digital Sky Survey image of the 212 galaxies in this sample. Images are 5' x 5' centered on the best position as given by NED. This sample spans a range of morphologies as can be seen here.

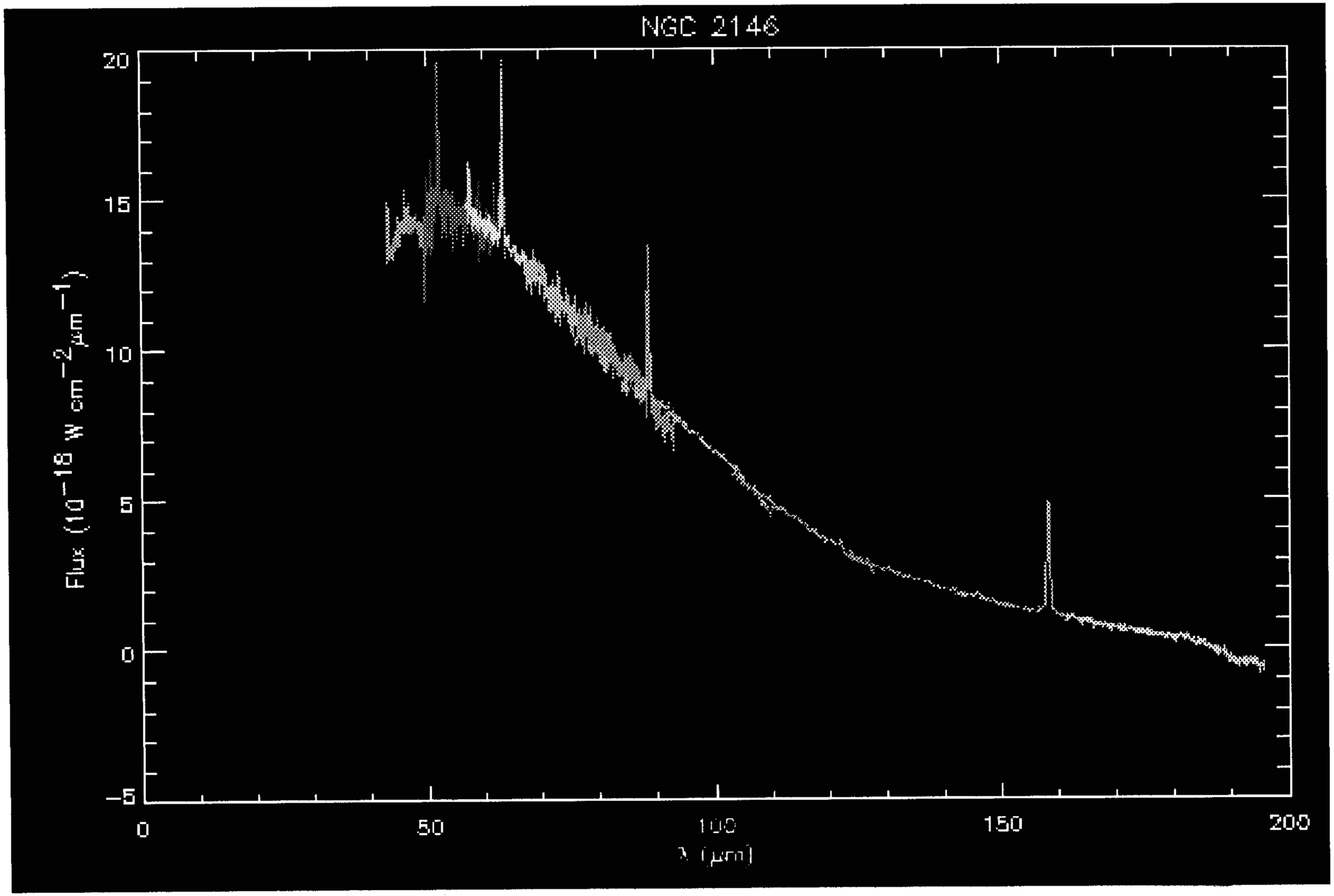

Figure. An example ISOLWS L01 full grating observation (43-197μm) of the galaxy NGC 2146. The far-infrared fine structure lines [OIII] 52μm, [NIII] 57μm, [OI] 63μm, [OIII] 88μm, and [CII] 158μm are easily identifiable on top of the continuum emission from the galaxy.

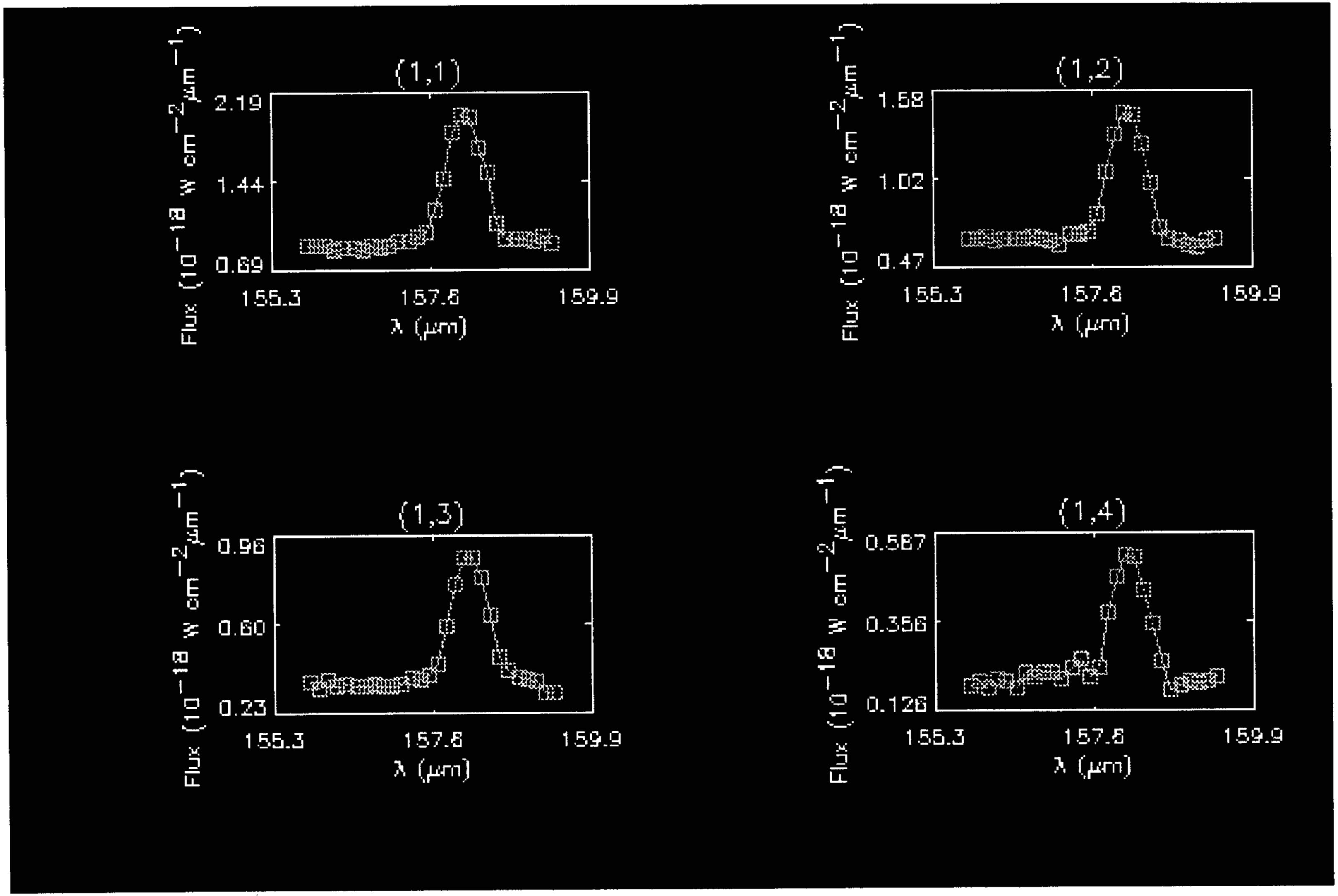

Figure. [CII] 158μm line observations taken in the ISOLWS L02 raster mode. Four raster positions were observed for the galaxy NGC 891 with [CII] present in the 75" beam at each position.

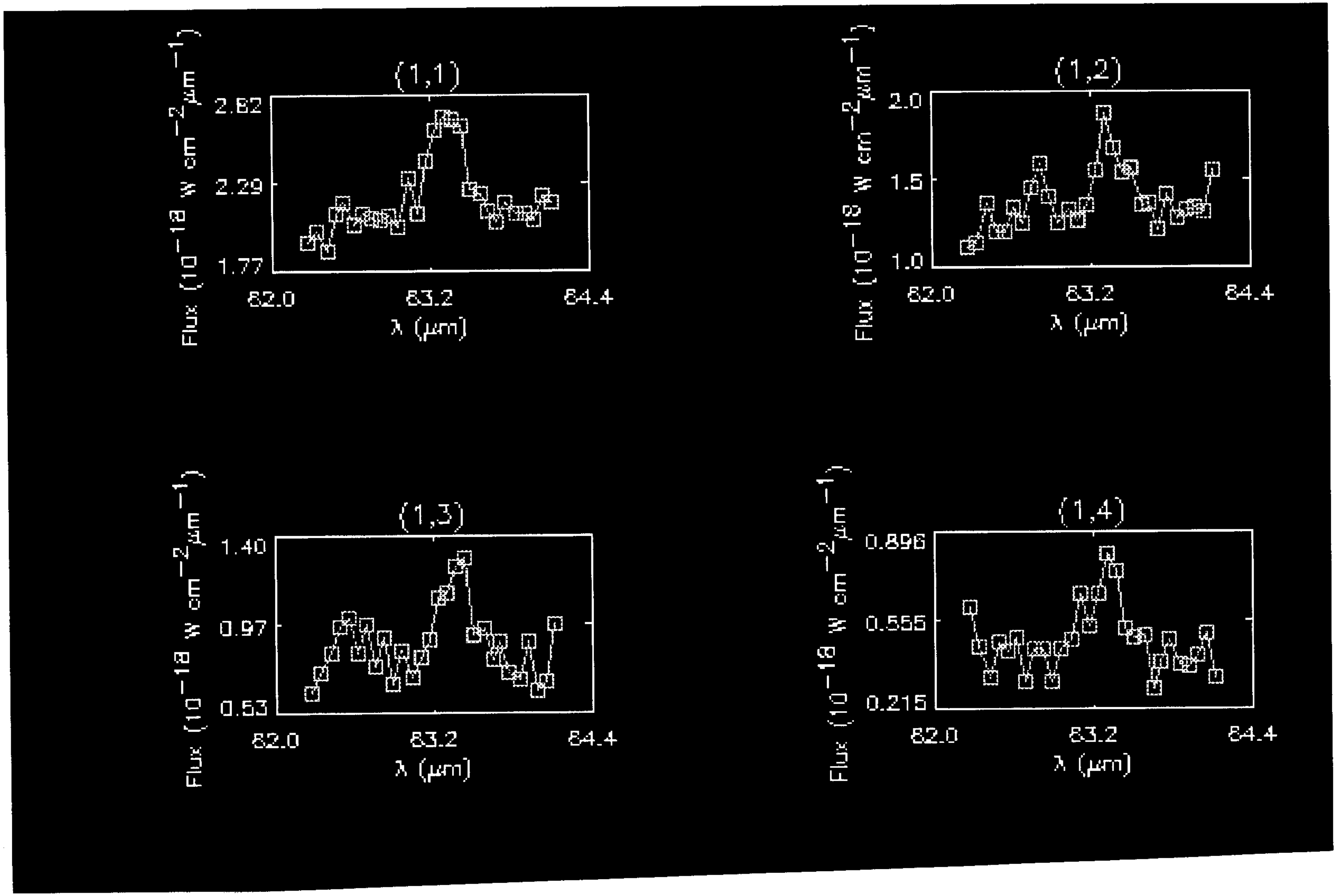

Figure. [OI] 63μm line observations taken in the ISOLWS L02 raster mode. Four raster positions were observed for the galaxy NGC 891 with [OI] present in the 75" beam at each position.

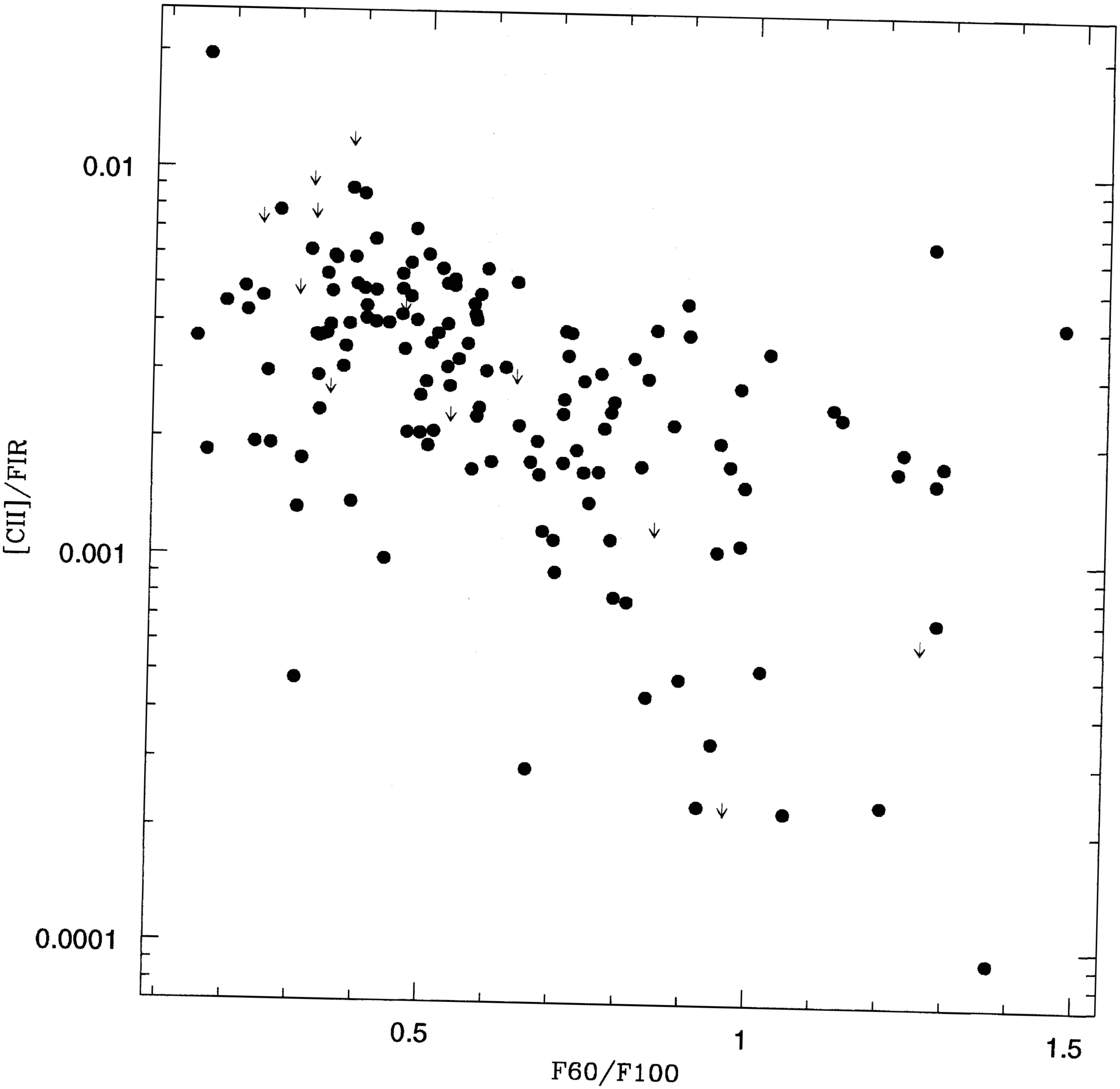

Figure. [CII]/FIR ratio plotted against the IRAS F60μm/F100μm ratio. The F60mm/F100mm ratio is a measure of the dust temperature and star formation activity in a galaxy. 3-σ upper limits are plotted as red arrows. There is a clear downward trend in [CII]/FIR ratio between F60μm/F100μm = 0.4 and 1.4. For F60μm/F100μm < 0.3, there is a hint of a gradual turnover and decrease in the [CII]/FIR ratio. This may be due to quiescent galaxies which have more dust heating from an older low-mass stellar population, producing little UV, and thus, little [CII] emission.

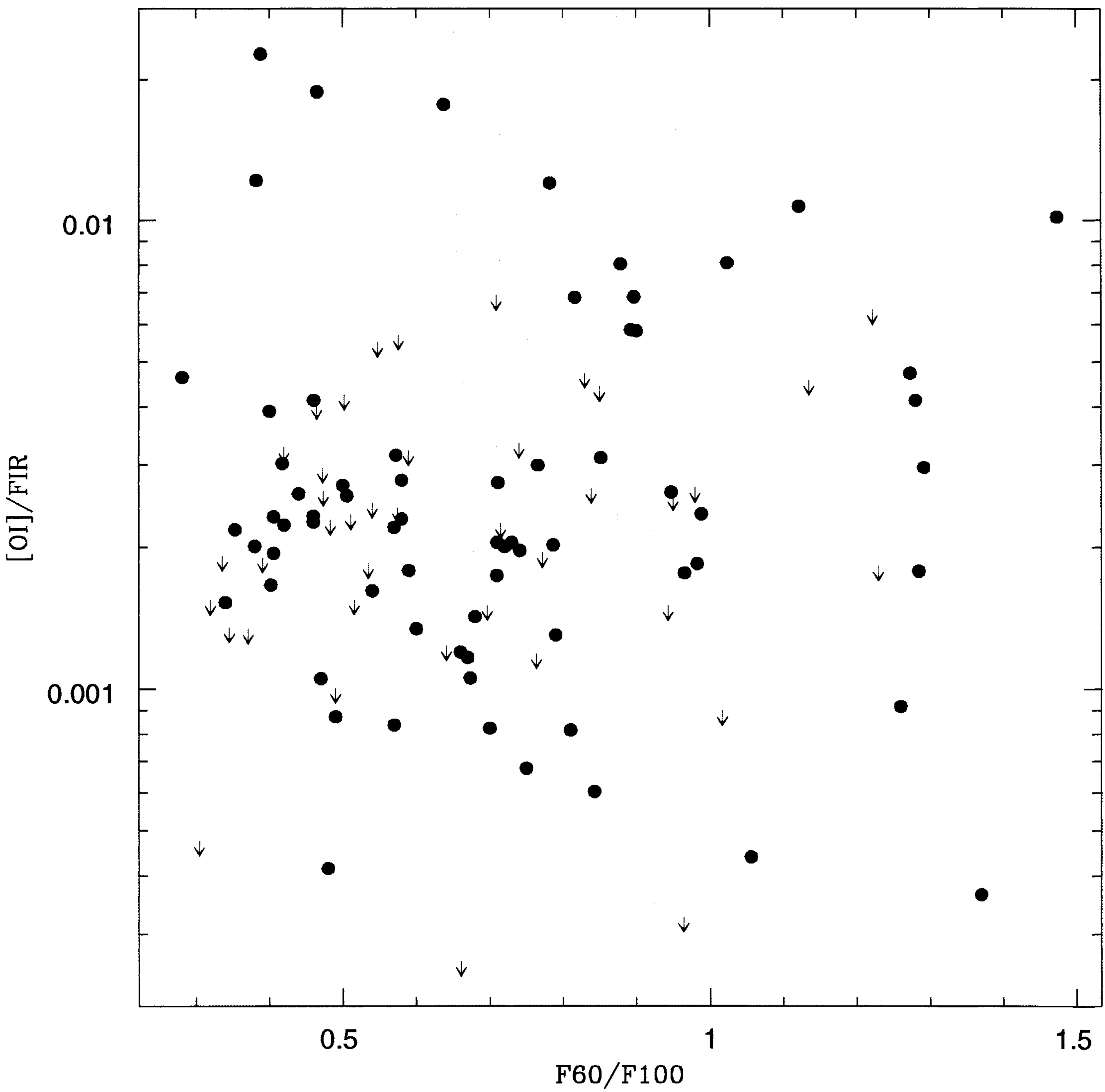

Figure. [OI]/FIR ratio plotted against the IRAS F60μm/F100μm ratio. [OI] traces FIR as can be seen here. 3-σ upper limits are plotted as red arrows. There appears to be two distinct populations on this plot which may be attributed to morphology.

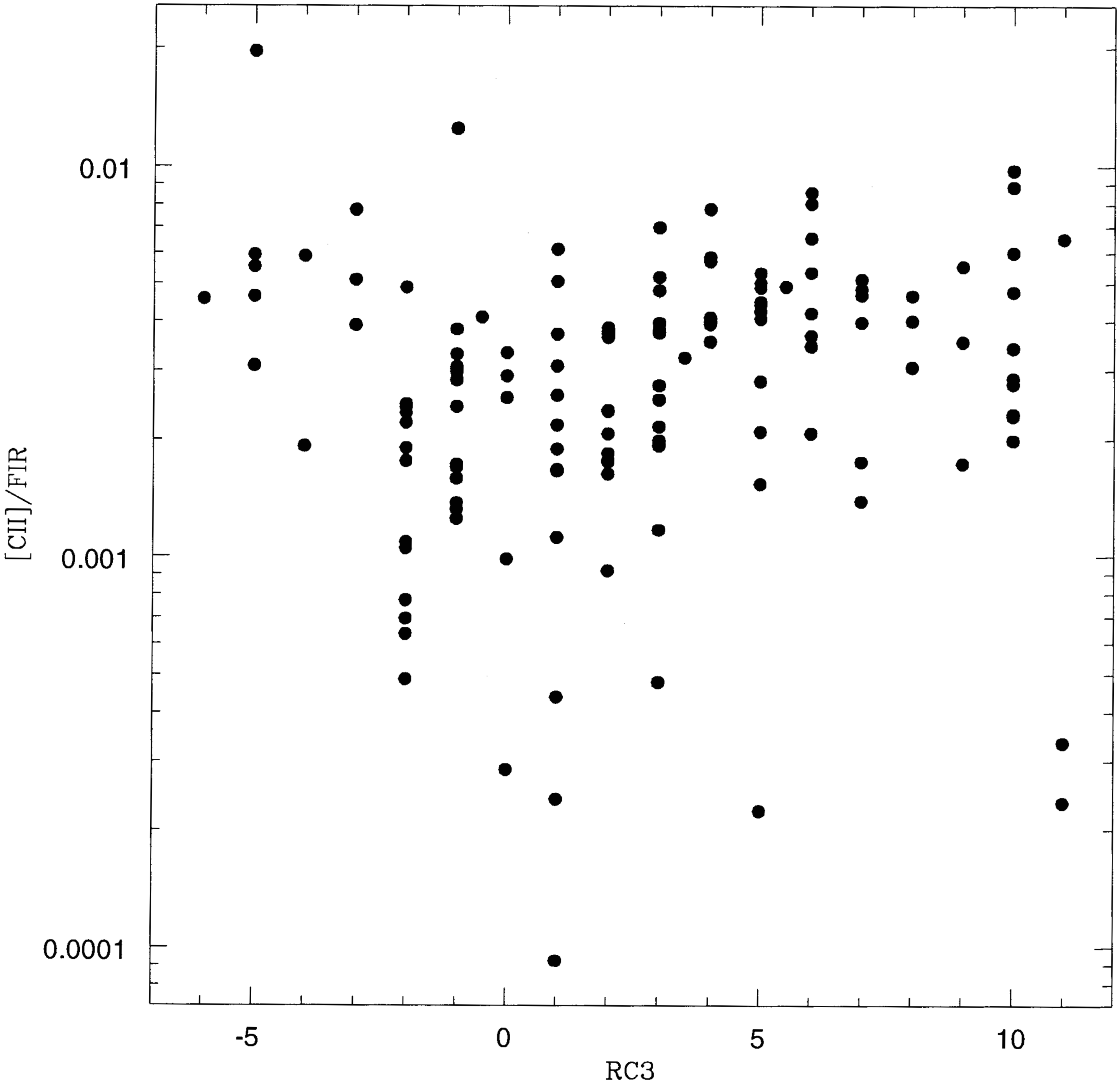

Figure. [CII]/FIR ratio against RC3 type. There is a difference in this ratio for RC3 types -1 to 3 against types later than 5. Galaxies with larger [CII]/FIR continuum ratios tend to have later Hubble types. Massive star formation activity increases with increasing lateness. This correlation may be proof of that gas heating is produced by the photoelectric effect on dust grains, induced by soft-UV photons from intermediate mass stars (Tielens & Hollenbach (1985) and Pierini et al. (1999)).